EXHIBIT D

Handbook of Optical Design

Second Edition

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Preface to the Second Edition

The first edition of this book was used by our students in a lens design course for several years. Taking advantage of this experience, this second edition has been greatly improved in several aspects.

Most of the material in the original second chapter was considered quite important and useful as a reference. However, to make an introductory course on lens design more fluid and simple, most of the material was transferred to the end of the book as an Appendix. In several other sections the book was also restructured with the same objective in mind.

Some of the modifications introduced include the clarification and a more complete explanation of some concepts, as suggested by some readers. Additional material was written, including additional new references to make the book more complete and up to date. We will mention only a few examples. Some gradient index systems are now described with greater detail. The new wavefront representation by means of arrays of gaussians is included. The Delano diagram section was enlarged. More details on astigmatic surfaces with two different curvatures in orthogonal diameters are given.

We would like to thank our friends and students who used the previous edition of this book. They provided us with many suggestions and pointed out a few typographical errors to improve the book.

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Preface to the First Edition

This is a book on the general subject of optical design, aimed at students in the field of geometrical optics and engineers involved in optical instrumentation. Of course, this is not the first book in this field. Some classic, well-known books are out of print however, and lack any modern topics. On the other hand, most modern books are generally very restricted in scope and do not cover important classic or even modern details.

Without pretending to be encyclopedic, this book tries to cover most of the classical aspects of lens design and at the same time describes some of the modern methods, tools, and instruments, such as contemporary astronomical telescopes, gaussian beams, and computer lens design.

Chapter 1 introduces the reader to the fundamentals of geometrical optics. In Chapter 2 spherical and aspherical optical surfaces and exact skew ray tracing are considered. Chapters 3 and 4 define the basic concepts for the first- and third-order theory of lenses while the theory of the primary aberrations of centered optical systems is developed in Chapters 5 to 7. The diffraction effects in optical systems and the main wave and ray methods for lens design evaluation are described in Chapters 8, 9, and 10. Chapters 11 to 17 describe some of the main classical optical instruments and their optical design techniques. Finally, Chapter 18 studies the computer methods for optical lens design and evaluation.

In conclusion, not only is the basic theory treated in this book, but many practical details for the design of some optical systems are given. We hope that this book will be useful as a textbook for optics students, as well as a reference book for optical scientists and engineers.

We greatly acknowledge the careful reading of the manuscript and suggestions to improve the book by many friends and colleagues. Among these many friends we would like to mention Prof. Raúl Casas, Manuel Servín, Ricardo Flores, and several of our students. A generous number of members of the research staff from Optical Research Associates provided a wonderful help with many constructive criticisms and suggestions. Their

number is large and we do not want to be unfair by just mentioning a few names. We also acknowledge the financial support and enthusiasm of the Centro de Investigaciones en Optica and its General Director Arquímedes Morales. Last, but not least, the authors greatly acknowledge the encouragement and understanding of our families. One of the authors (D.M.) especially thanks his sons Juan Manuel and Miguel Angel for their help with many of the drawings and the word processing of some parts.

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Contents

12.2.2 Telephoto Lens

The telephoto lens has two basic elements: a positive lens in the front and a negative lens in the back. The effective focal length of the system is larger than the total length, from the front lens to the focal plane, of the system. This kind of system is used whenever there is a need for a compact system, as compared with its focal length. A telephoto lens is the lens equivalent of a Cassegrain telescope. The telephoto ratio is defined as the ratio of the total length of the system to the effective focal length as follows:

$$k = \frac{t + F_B}{F} \tag{12.1}$$

where t is the lens separation, F is the effective focal length, and F_B is the back focal length. Then, the focal length for the front element may be written

$$f_a = \frac{Fd}{F(1-k)+d} \tag{12.2}$$

and the focal length for the second element is

$$f_b = \frac{(f_a - d)(kF - d)}{(f_a - kF)} \tag{12.3}$$

Typical values for the telephoto ratio are around 0.8.

A common problem with telephoto designs is the presence of distortion, but it may be reduced as described by Kazamaki and Kondo (1956). A telephoto lens, designed by Kingslake, redesigned by Hopkins, and reported by Smith and Genesee Optics Software (1992) is described in Table 12.3 and shown in Fig. 12.2.

An inverted telephoto lens is normally used to obtain wide-angle fields. When the field is very large, this lens is sometimes wrongly called a fisheye lens. The strong distortion of this system may be compensated by introducing a positive lens in front of the negative element.

These lenses have the property that their back focal length is longer than their effective focal length, which is useful in certain applications.

12.2.3 Cooke Triplet

H. Dennis Taylor, working for the Cooke and Sons company in York, England, in 1893, invented this famous design. This system has just enough